DE LORENZO

DL 2594N

MICROWAVE TRAINER

USER MANUAL

DE LORENZO

Content

Preface	page 3
About This Manual	page 5
1 Composition, Operation & Maintenance	page 7
1.1 The training kit DL 2594N of 3 cm Waveguide Experiment System	page 8
1.2 Technical Descriptions of Components Used in DL 2594N	page 11
2 Installation of the DL 2594N Trainer	page 43
2.1. The Way to Use the Component with IN/OUT Directions	page 45
2.2. The Way to Use the Component with Directions	page 46
2.3. The Way to Use the Power Meter	page 47
2.4. The DL 2594N trainer kit content	page 49
2.5. Technical specifications and features	page 52
3 Theoretical part	page 55
3.1. A few notions. General background	page 57
3.2. The microwave spectrum	page 58
3.3. The electromagnetic spectrum	page 59
3.4. Transmission line (TL) theory (TEM Line)	page 59
3.5. Transmission lines with sinusoidal excitation	page 61
4 Experimental Section	page 63
4.1. Experiment 1: Crystal detector	page 65
4.2. Experiment 2: Propagation modes, wavelength and phase velocity in waveguide	page 77
4.3. Experiment 3: Q Value and bandwidth of a resonance cavity	page 87
4.4. Experiment 4: Power Measurement	page 95
4.5. Experiment 5: Standing Wave Measurement	page 105
4.6. Experiment 6: Study of microwave propagation in waveguide	page 111
4.7. Experiment 7: Basic properties of a directional coupler	page 119
4.8. Experiment 8: Attenuation Measurement	page 127
4.9. Experiment 9: Study of a waveguide Hybrid – Tee	page 133
4.10. Experiment 10: Emission and reception using Horn antennas	page 143
References	page 149

Preface

The microwave radio communications network plays a very important role in current times. Higher frequency signals travel across the ionosphere, but experience distortion, which decreases with frequency. Microwave signals, well above the ionospheric cut-off, are hardly affected at all, at sufficiently small power levels. For these reasons, microwaves are utilized for satellite communications and space transmissions. The innovative technologies are used to make an advanced telecommunication system as a major trend asks for it. To answer the increasingly diversified needs for training in this wide telecommunication system management, a few important training programs have been developed.

The DL 2594N trainer has been designed to start with a few related concepts providing in-depth coverage of the basic topics related to the propagation of the microwave electromagnetic field through rectangular metal guides, as well as the interaction between the microwave field and various conductive or dielectric environments.

The set of experiments then builds on the knowledge gained by the student through these basic courses to provide training in more advanced topics such as electromagnetic field, microwave propagation through wave guides, the conditions in which the phenomena of stationary wave, reflected wave, resonance and attenuation occur along the propagation direction.

The destination of the designed trainer

1. The DL 2594N trainer is dedicated, first of all, to the people with some electromagnetism and telecommunications background who want to understand the use of the devices and of the telecommunication technologies in ultra-high frequencies.
2. Secondly, it can be used also as a trainer by people with basic technical knowledge, if they understand the main physical phenomena that occur in the propagation of the electromagnetic field of microwave when it is directed by metal wave guides.
3. The DL 2594N trainer exemplifies step by step, in a logical sequence, the role of each component used in the electronic circuits in the microwave field, as well as the role of the measuring apparatuses used in the quantitative evaluation of the main physical magnitudes and in the study of the

propagation of the microwave electromagnetic field, through the elements that make up the microwave installations.

4. With the provided documentation, the user is able to continue or to develop new applications of the trainer.
5. As it can be seen, by having in the laboratory such complex experiments, teachers, instructors, or any other people involved in education and training can design their own teaching plan in different fields of education - from the basics of the microwave propagation study up to the telecommunication technologies in ultra-high frequencies.

3.

Theoretical part

Introduction. Application areas of microwaves

This first theoretical part conveys a basic knowledge on the physics of microwaves. Microwaves are generated by a microwave signal source (DL 2594N device) and their propagation in conjunction with rectangular waveguides (DL 2594.1 to DL 2594.14) is examined in detail.

- Characteristics of the electromagnetic waves
- Crystal detector
- Recording a current-voltage characteristic
- Transmission line theory and line variables
- Wave propagation in waveguides
- Standing waves, short-circuits, reflection and matching
- Standing-wave ratio
- Power reduction and thermal load
- Measuring waveforms in waveguides with the aid of a slotted line
- TE, TM and hybrid waveguides
- Waveguide dimensions and operating frequency
- Dielectrics in a waveguide

Prerequisites for successfully working through this first theoretical part include:

- Knowledge of DC and AC technology
- Fundamentals of transmission line theory: equivalent circuit diagram for an electrical transmission line and quantities per unit length
- Physics of wave propagation
- Understanding of complex numbers expressed using "j"

3.1. A few notions. General background.

Frequency Definition: The frequency range extending from 300 MHz up to 300 GHz is generally known as microwaves. These limits are to some extent arbitrary.

Wavelength Definition: From $c = \lambda \cdot f$ (in vacuum), λ is between 1m and 1mm.

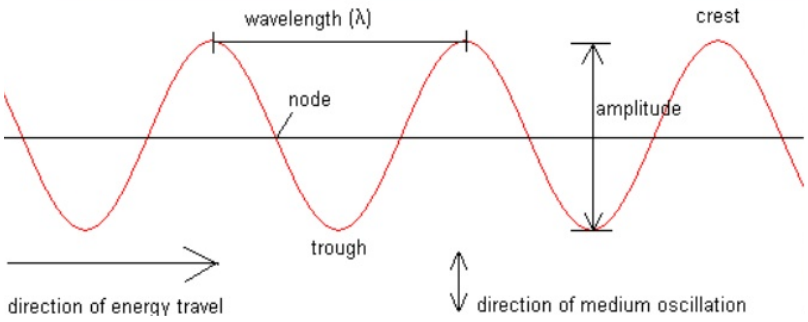


Figure 3.1. Waves main parameters

Energy of a Microwave Photon: A microwave photon has an energy in the range roughly $1.2x10^{-6}$ - $1.2x10^{-3}$ eV (calculated from energy = h·f where h = $6.63x10^{-34}$ J s). Non ionization.

Order of Magnitude of the Periods: The period T = 1/f is between 3ns (nanoseconds) and 3 ps (picoseconds).

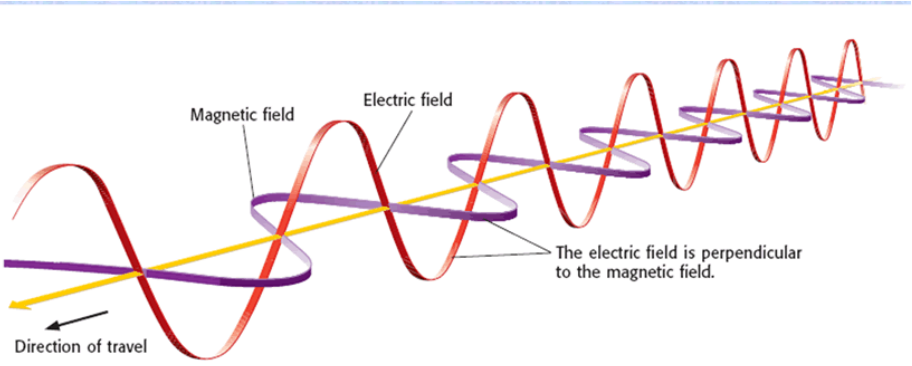


Figure 3.2. The orthogonality property of electromagnetic waves. The pattern.

Dimensional Comment: The wavelength of a microwave signal is of the same order of magnitude as the devices used to produce and transmit it. It is not possible to assume that devices are merely dimensionless points in free space as it is done in circuit theory approximations. Also, the term voltage is not defined in a unique way, since the electric field is not derived from a scalar potential. On the other hand, it is neither possible to assume that devices are too large with respect to the wavelength, as it is the case for the geometrical optics. Microwave problems must be considered in terms of electric and magnetic fields as defined in Maxwell's model.

Bandwidth: The rate of transmission of a channel being directly proportional to its bandwidth. A simple calculation shows that, over the range of 300 MHz to 300 GHz frequency range, 999 times more information can be transmitted over a specified time period than in all the lower frequency bands taken together (0 - 300 MHz). A 1% bandwidth at 600 MHz is 6 MHz (the bandwidth of one channel), while at 60 GHz a 1% bandwidth is 600 MHz (about 100 TV channels).

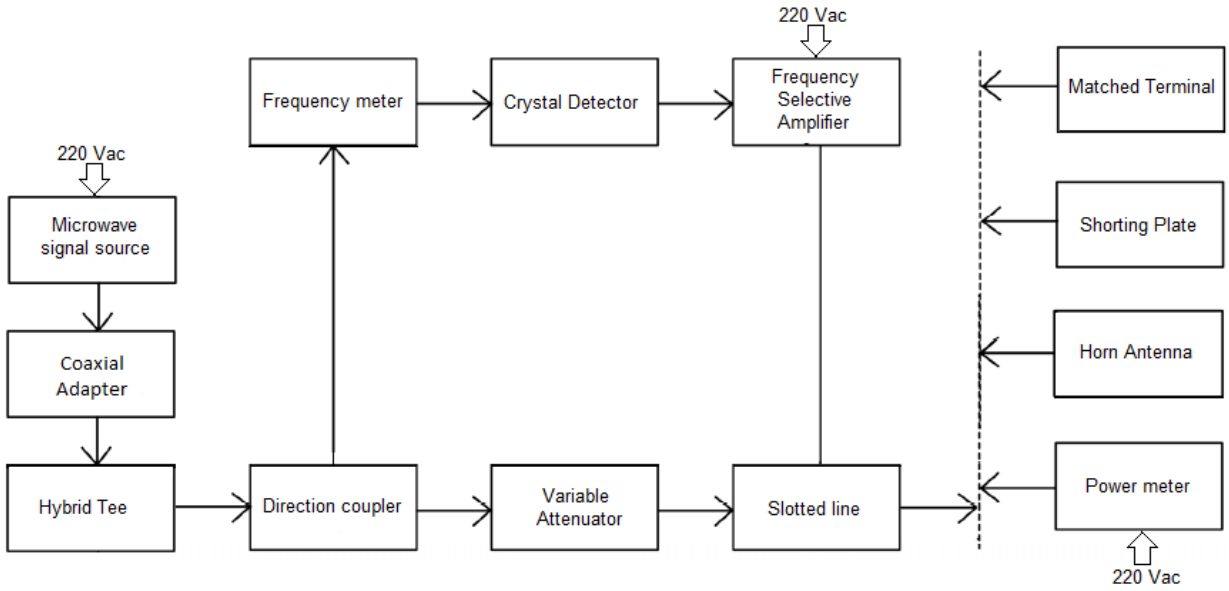
4.

Experimental Section

Introduction

Microwave and light waves are both electromagnetic waves. They share the common phenomena of all waves, such as reflection, refraction, polarization, interference, and diffraction. However, as the wavelength of a microwave is about 4 orders larger than that of a visible light wave, the experimental phenomena and apparatus of the microwave are different.

DL 2594N 3cm waveguide experiment system module schematic diagram



This diagram is only informative because in the experiments that will be presented below, only some of the devices and components will be used.

The microwave absorption is directed by the dielectric constant of the tissue.

As the speed of the electromagnetic waves is proportional to the reciprocal value of the square root of the dielectric constant, the resulting wavelength in the tissue can drop to a fraction of the wavelength in air; e.g., at 10 GHz the wavelength can drop from 3 cm to about 3.4 mm.

Because the oscillator used in this experiment unit has a relatively small power, the output is not dangerous to other body parts, but eyes can be permanently damaged!!!

4.1. Experiment 1: Crystal detector

Objectives

- To learn the basic theory and the operation of the crystal detector.

4.1.1. Theory:

A. Crystal detector.

The crystal detector is a device capable of detecting microwave signals based on the "square law" characteristics.

Point contact germanium or silicon crystal diodes are the most popular type of crystal detectors. Sometimes, a bolometer is used for microwave detection, although the device is mainly intended for microwave power measurements.

A typical crystal detector circuit and associated characteristic curves of a crystal detector are presented in Figure 4.1.1 and Figure 4.1.2. The filter (input high-pass) is to separate the microwave frequencies from the DC output.

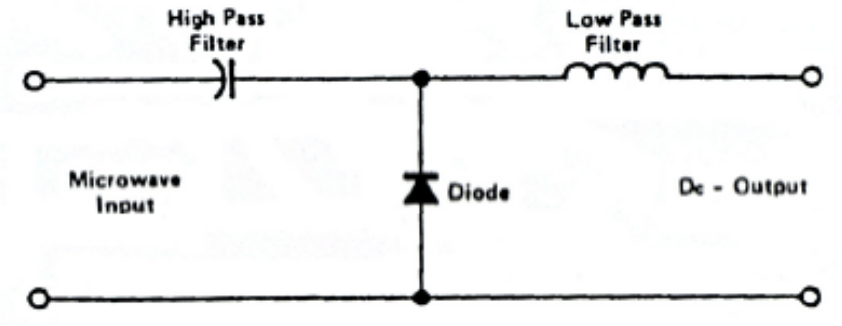


Figure 4.1.2. Typical crystal detector circuit

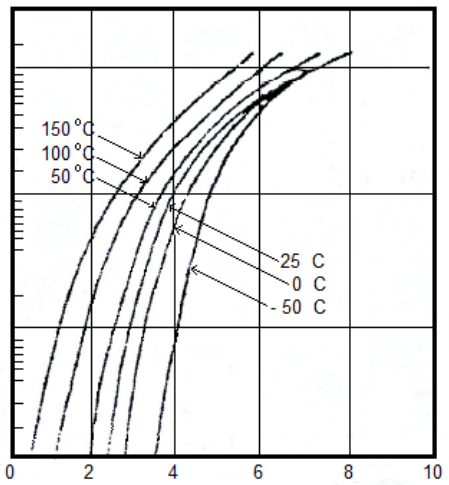


Figure 4.2. The V-I characteristics of a crystal diode. Forward Voltage

In Figure 4.1.2, we are interested in finding the relationship between the diode current and the diode voltage.

$$i = a_0 + a_1V + a_2V^2 + a_3V^3 \qquad (4.1\text{-}1)$$

Normally, the first three terms are sufficient to approximate the entire function. If the voltage is expressed as:

$V = A\cos\omega t$; where A is the amplitude and ω is equal to $2\pi f$

Substituting V into (4.1-1):

$$i = a_0 + a_1 (A\cos\omega t) + a_2 (A\cos\omega t)^2 + \ldots \qquad (4.1\text{-}2)$$

Using:

$$\cos^2\omega t = 1/2(1 + \cos^2\omega t) \qquad (4.1\text{-}3)$$

$$i = a_0 + a_1 (A\cos\omega t) + (a_2A^2/2) (A\cos 2\omega t) + \ldots \qquad (4.1\text{-}4)$$

Now, the characteristics of the square-law become clear. In equation (4.1-4), the DC component is contained in the $a_2A^2/2$ term.

The second harmonics is expressed as $(a_2A^2/2)$ $(A\cos 2\omega t)$. Therefore, we can say that the current in the detector is proportional to the square of the amplitude A of the microwave voltage.

This concept is only valid up to a certain signal level. At higher signal levels, more terms may be needed in (4.1-4) and the diode is no longer considered as a square-law device.

In Figure 4.1.3, a complete equivalent circuit of a detector is presented.

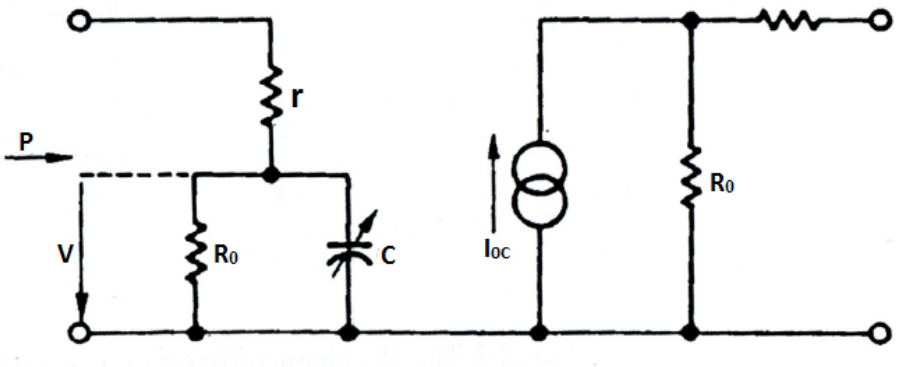


Figure 4.1.3. Equivalent circuit of a detector.

In Figure 4.1.3., R_0 and C represent the impedance of the junction and r is the body resistance of the diode. A figure of merit of a detector is the voltage and current sensitivity of the detection function which is

expressed as:

$$Voltage\ sensitivity = \frac{Open\ circuit\ voltage}{Input\ power} = \frac{R_0 I_{dc}}{P_{in}} \quad (4.1\text{-}5)$$

$$Current\ sensitivity = \frac{Short\ circuit\ voltage}{Input\ power} = \frac{R_0 /(r + R_0)}{P_{in}} \quad (4.1\text{-}6)$$

In order to maximize the output power, it is necessary to match the microwave impedance of the diode to the characteristic impedance of the waveguide.

Another reason for the impedance matching is to minimize the reflection from the detector since the measurement accuracy is affected by the reflection.

The minimum signal level a diode can detect depends on the noise in the diode.

The ability of a diode to detect a signal in the presence of noise is called the tangential sensitivity (TSS) of a detector.

The ability of a diode to detect a signal in the presence of noise is called the tangential sensitivity (TSS) of a detector.

A graphical illustration of the concept of TSS is sketched in Figure 4.1.4.

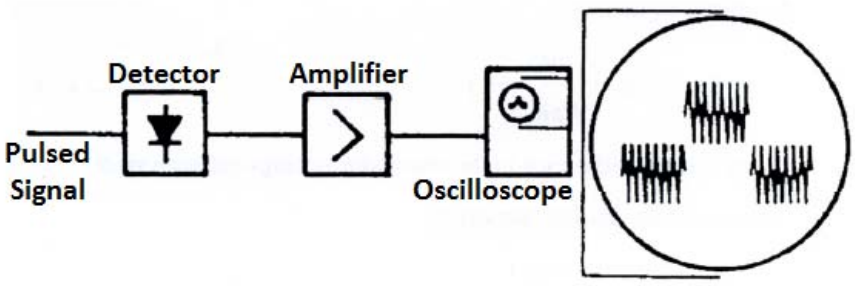


Figure 4.1.4. The TSS of a diode.

In Figure 4.1.4, a microwave signal which is pulse modulated is detected, amplified and displayed on an oscilloscope. The real meaning of TSS is there has to be a minimum microwave power level to make the pulse ride above the noise.

The TSS of a detector is very much dependent upon the bandwidth of the amplifier which follows the detector since the noise amplitude on the

scope is determined by the bandwidth. One MHz bandwidth and -50dBm of TSS are typical values of a microwave detector.

4.1.2. Experiment Procedure

A. Square wave modulation.

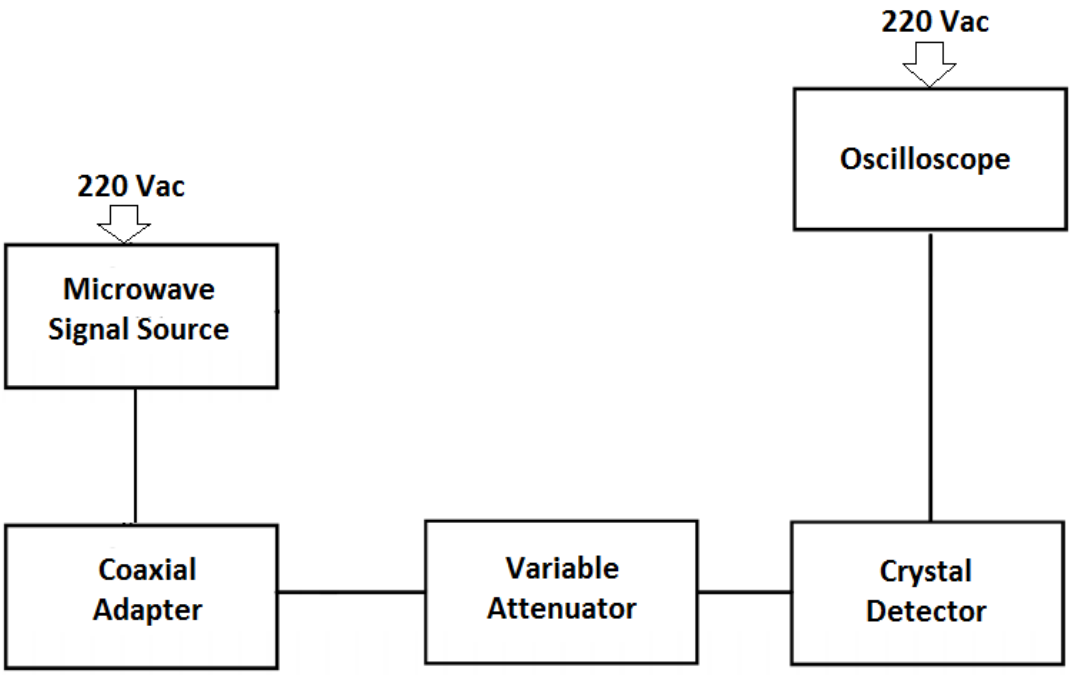


Figure 4.1.5. Schematic representation of the experiment.

Summary of the Experiments

(1) Set up the equipment as shown in Figure 4.1.5.

(2) Power up the Signal Source.

(3) Set the variable attenuator to 10.

(4) Switch on the signal 1KHz.

(5) Adjust the scope so that the top of the square wave aligns to the zero level on the screen.

(6) Adjust the attenuator so that the bottom of the square wave aligns to the zero level on the screen.

(7) Calculate the modulation depth using the following equations.

$$AdB = 20\log\left(\frac{V\max}{V\min}\right) \qquad (4.1\text{-}7)$$

where A is the difference in the attenuator settings between step (3) and (6) and m is the modulation depth.

$$m = \frac{V\max / V\min^{-1}}{V\max / V\min^{+1}} \qquad (4.1\text{-}8)$$

A sketch of the waveforms of the square wave modulation and detection is shown in Figure 4.1.6.

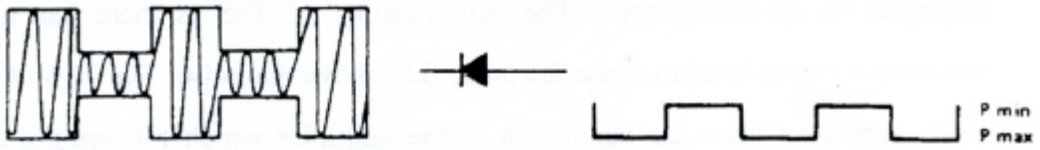


Figure 4.1.6. Square wave modulation and detection.

As one can see from Figure 4.1.6, the attenuator setting deviation A can be expressed as:

$$AdB = 10\log\frac{P\max}{P\min} = 20\log\frac{V\max}{V\min} \qquad (4.1\text{-}9)$$

B. The square law characteristics of a crystal detector.

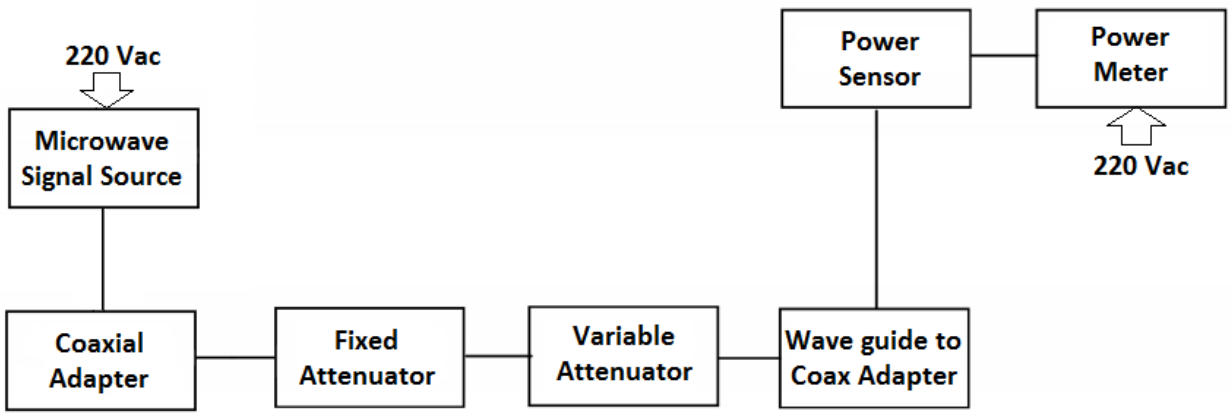


Figure 4.1.7. Schematic representation of the experiment.

Figure 4.1.8. Real representation of the experiment.

To identify each component in the assembly, it is recommended to view and to zoom the following figure.

Figure 4.1.9. Real representation of the experiment with inscriptions view.

Summary of the Experiment

(1) Apply power to the Gunn oscillator. Also apply 1kHz square wave.

At this point, modulation should take place.

(2) Set the variable attenuator to 0. The power meter should indicate between 2 dBm and 4 dBm.

Referring to the conversion table on the power meter, change mW reading to dBm. For example, 0.1mW is equal to -10dBm.

(3) As shown in Figure 4.1.10, replace the waveguide to the coax adapter, the power sensor and the power meter with a crystal detector and a SWR indicator. Adjust the modulating frequency such that the deflection of the SWR meter is maximized.

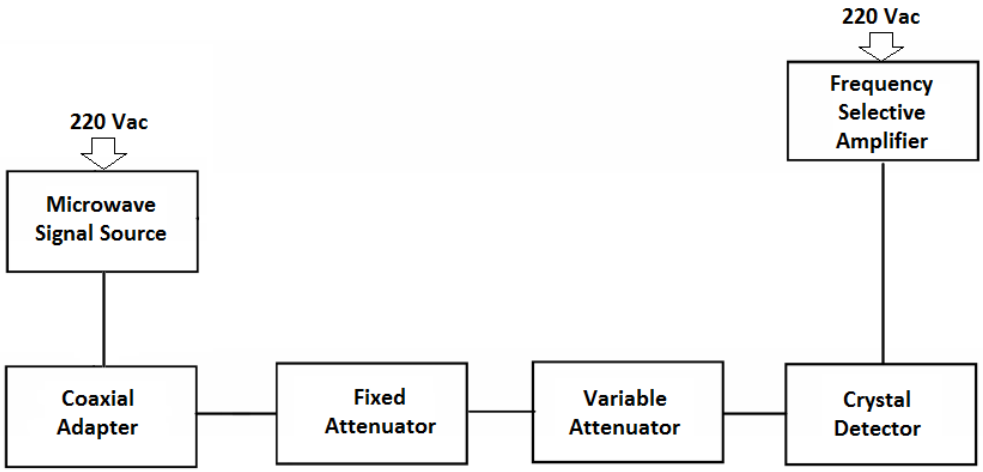


Figure 4.1.10. Setup diagram for measuring the square law characteristics of a crystal detector.

Figure 4.1.11. Real representation of the experiment.

To visually distinguish the inscriptions on each component of the assembly, it is recommended to zoom in on this figure.

In the images in the following figures the manual action modes for assembling the components in the assembly are presented. These techniques, used and shown in the figures, are valid for assembling the microwave components in all the experiments in this manual.

Figure 4.1.12. How to assemble components using screw, nut, and fixed key.

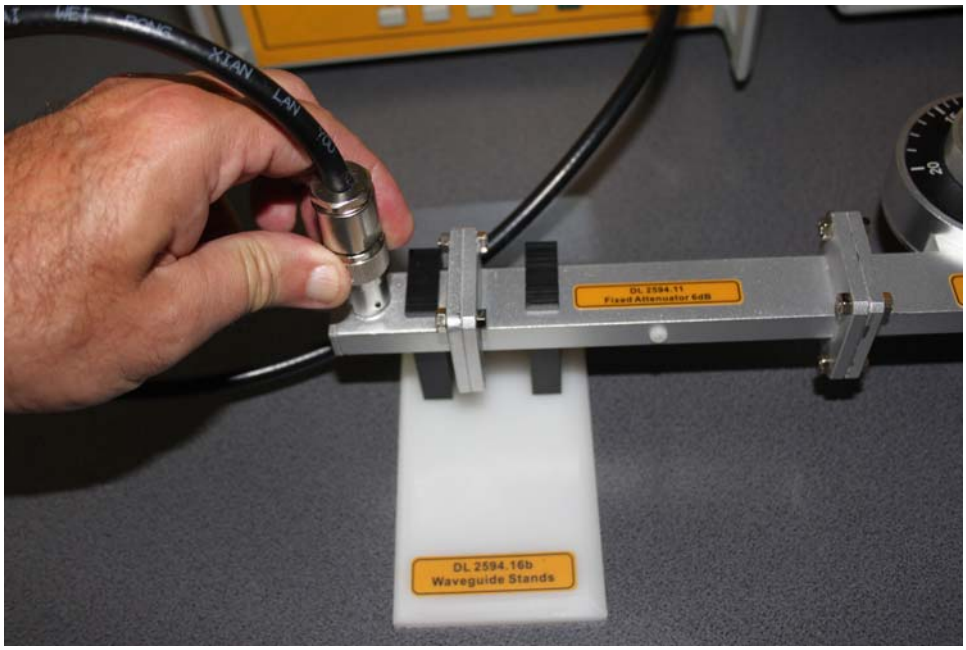


Figure 4.1.13. How to connect the Coaxial Adapter to the line cord with the Microwave Signal Source.

Figure 4.1.14. How to connect the line cord with the Microwave Signal Source.

Figure 4.1.15. How to connect the line cord with the Power Meter.

Figure 4.1.16. How to connect the Power Sensor with the Coaxial Adapter.

Figure 4.1.17. How to connect the BNC line cord with the SWR Meter.

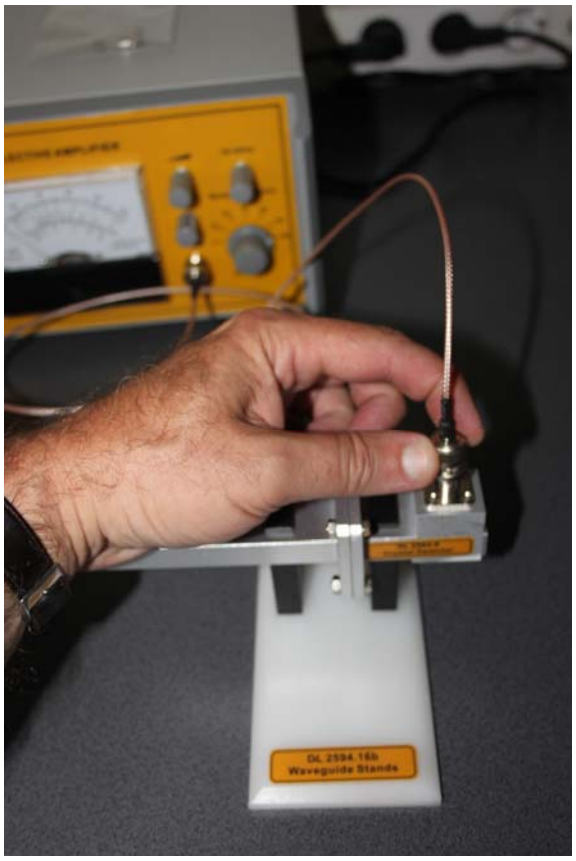


Figure 4.1.18. How to connect the BNC line cord with the Crystal Detector.

(4) Select a range on the SWR meter. Adjust the gain control of the SWR meter to obtain a convenient reading on the dB scale. Once the range and the gain control are set, do not touch the gain control.

(5) Vary the attenuator from 0 to 20 in 1 by 1 step increment. At each step, record the SWR meter deflection (in dB) (using the Frequency Selective Amplifier) and the gain range in Table 4.1-1.

Table 4.1-1 Input power vs attenuation and SWR reading.

A	INPUT POWER	SWR - INDICATOR		DEFLECTION AND RANGE
		DEFLECTION	RANGE	
	dBm	dB	dB	dB